CSD 5180-81-1
August 14, 1981

BOOSTER SEPARATION MOTOR
FINAL DOCUMENTATION

UNITED TECHNOLOGIES CHEMICAL SYSTEMS

Contract No. NAS8-31672
IRD SE-019-024-2H(M), MA 10(M)

Prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
GEORGE C. MARSHALL SPACE FLIGHT CENTER
MARSHALL SPACE FLIGHT CENTER, ALABAMA 35812

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ILLUSTRATIONS

1.0 INTRODUCTION

This final documentation report covers the work accomplished during the Booster Separation Motor Development Program under contract No. NAS 8-31672. The contract, initiated on 25 August 1975 and completed on 30 June 1980, covered the design, development, fabrication, testing, evaluation, and flight qualification of the Space Shuttle Booster Separation Motor (BSM). It also included delivery of flight hardware to support the research and development (R&D) flights of the Space Shuttle.

This report is prepared in accordance with the instructions of Data Requirement No. MA 10(M) of the Information Requirement Document SE-019-024-2H(M), Exhibit L, of the contract. As such, the report provides a brief narrative for each of the program tasks or work statement paragraphs. These narratives summarize the purpose and scope, results, conclusions, and recommendations as appropriate for each task.

Section 2.0 of this report provides the reader with a program overview including a general description of the BSM hardware that was developed and a summary schedule so that the time relationships of the major tasks can be easily visualized.

To facilitate the direct correlation of this report to the statement of work (SOW), sections 3.0 through 8.0 are titled and numbered identically to the paragraphs of the SOW being addressed.

2.0 PROGRAM OVERVIEW

The Booster Separation Motor Program originally consisted of three phases: development, qualification, and delivery. As the program progressed and the solid rocket booster (SRB) functions became more definitized, additional criteria and requirements were imposed upon the BSM and the program evolved into six separate areas: development, prequalification, qualification, delivery, aging and surveillance, and humidity motor tasks. These are shown in the program schedule in figure 2-1.

The development of the basic motor was completed and critical design review (CDR was held within 17 months of preliminary design review (PDR), with a total of eight development motors successfully tested to demonstrate compliance with the requirements of the motor model specification.

The Aeroheat Shield (AHS) Program, consisting of three phases, was performed concurrently with the motor prequalification and qualification efforts and required 15 months from receipt of Change Order 28 (which defined configuration) to the successful test of prequalification unit No. 1 (PQ-1), equipped with a prototype AHS cover. This 15-month period included the failure analyses, redesign, and retest effort resulting from the failure of the AHS frangible link during ascent vibration of the PQ-1 motor. This failure added approximately 7 months to the qualification portion of the program.

The prequalification portion of the program became necessary because the redefinition of the environmental test requirements called for motor test demonstration prior to initiating qualification testing. Completion of the prequalification testing of one aft and one forward BSM, each equipped with its appropriate cover, was completed in October of 1978, after completion of the revised environmental test series described in subsection 2.1.8 and the fabrication of the AHS prototype cover.

The qualification portion of the BSM program consisted of testing of 14 motors, made up of 10 forward motors and four aft motors. These motors were separated into two groups, six statistical tests and eight environmental tests.

These motors were built and tested over 17 months and led to a successful design certification review (DCR) in March 1979 and a qualification certification review (QCR) immediately following in April 1979.

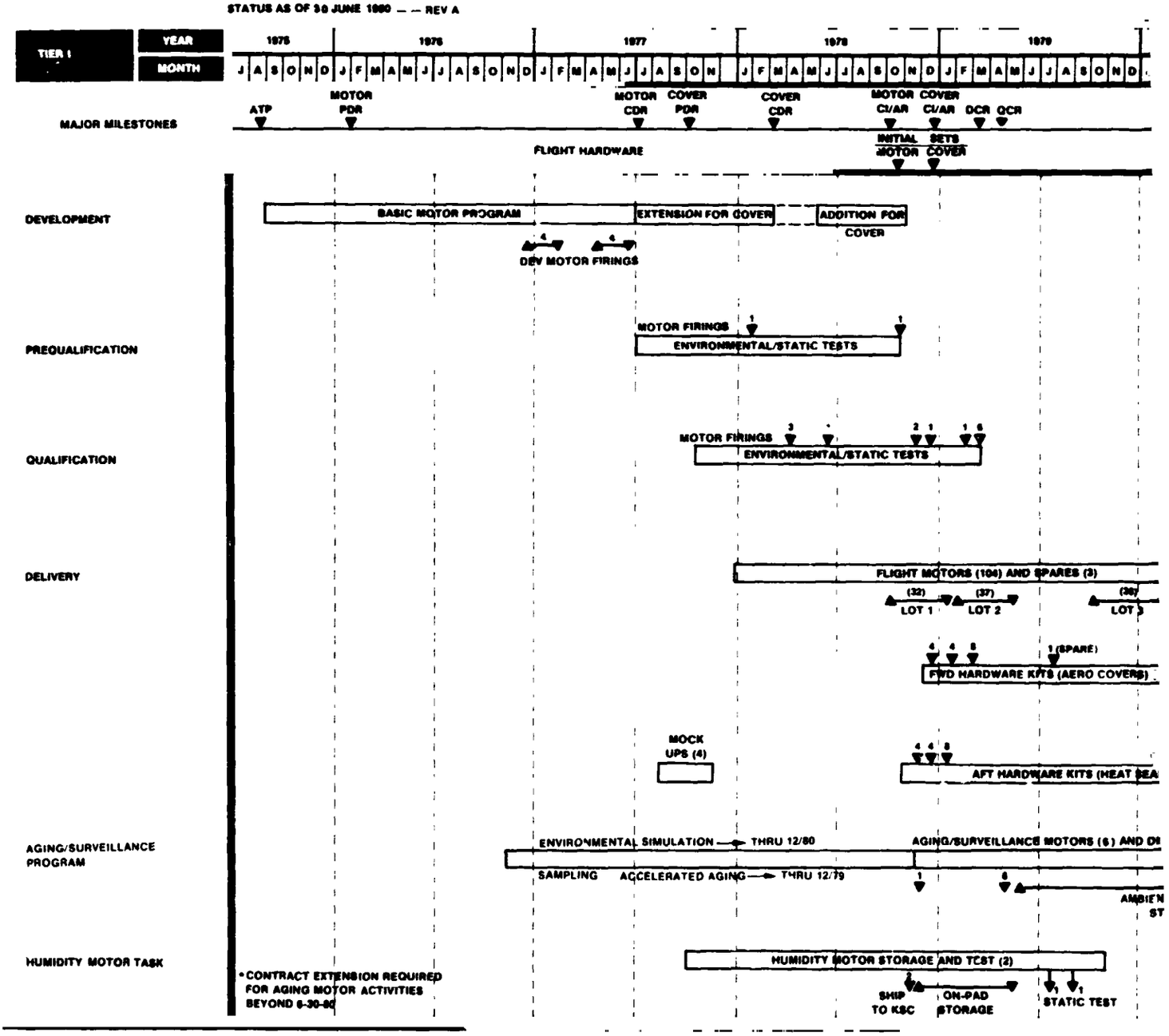
Four booster staging motor configurations were qualified for flight use:

Part No.	Description
B12095-01-01	Forward motors with transducer port plugged
B12095-02-01	Forward motors with pressure transducer installed
B12095-03-01	Aft motor with transducer port plugged
B12095-04-01	Aft motor with pressure transducer installed

The aft and forward motors differ mainly in the external cork insulation provided for the aft motor only and the unique type of nozzle covers used in the flight configuration of each motor. Figures 2-2 and 2-3 show the unique aft portions of the forward and aft motor flight configurations, respectively. Figures 2-4 and 2-5 show the forward and aft motors, respectively, in their shipping configurations. The shipping configurations are converted to flight configurations with the assembly of the appropriate aft or forward mechanical hardware set (insulated aft seal or aeroheat shield) at the launch sites. For the development flight motors, one in four was equipped with flight pressure transducers.

The flight delivery portion of the program consisted of the manufacture, assembly, acceptance test, and shipment of 107 BSM flight motors (including three spares) consisting of 54 of the forward and 53 of the aft configurations (three as spares). The flight motors were manufactured and delivered over a 30-month period, 15 months of which overlapped the qualification phase and 10 months of which overlapped the prequalification phase. This overlap period extended the final motor deliveries by almost 6 months and was caused primarily by the frangible link failure during a prequalification test and its subsequent resolution. CSD also delivered additional through-bulkhead initiators (TBIs) (see subsection 4.8.1) and spares (see section 5.0).

BOOSTER SEPARATION MOTC



FOLDOUT FRAME

EPARATION MOTORS

CHEMICAL SYSTEMS DIVISION

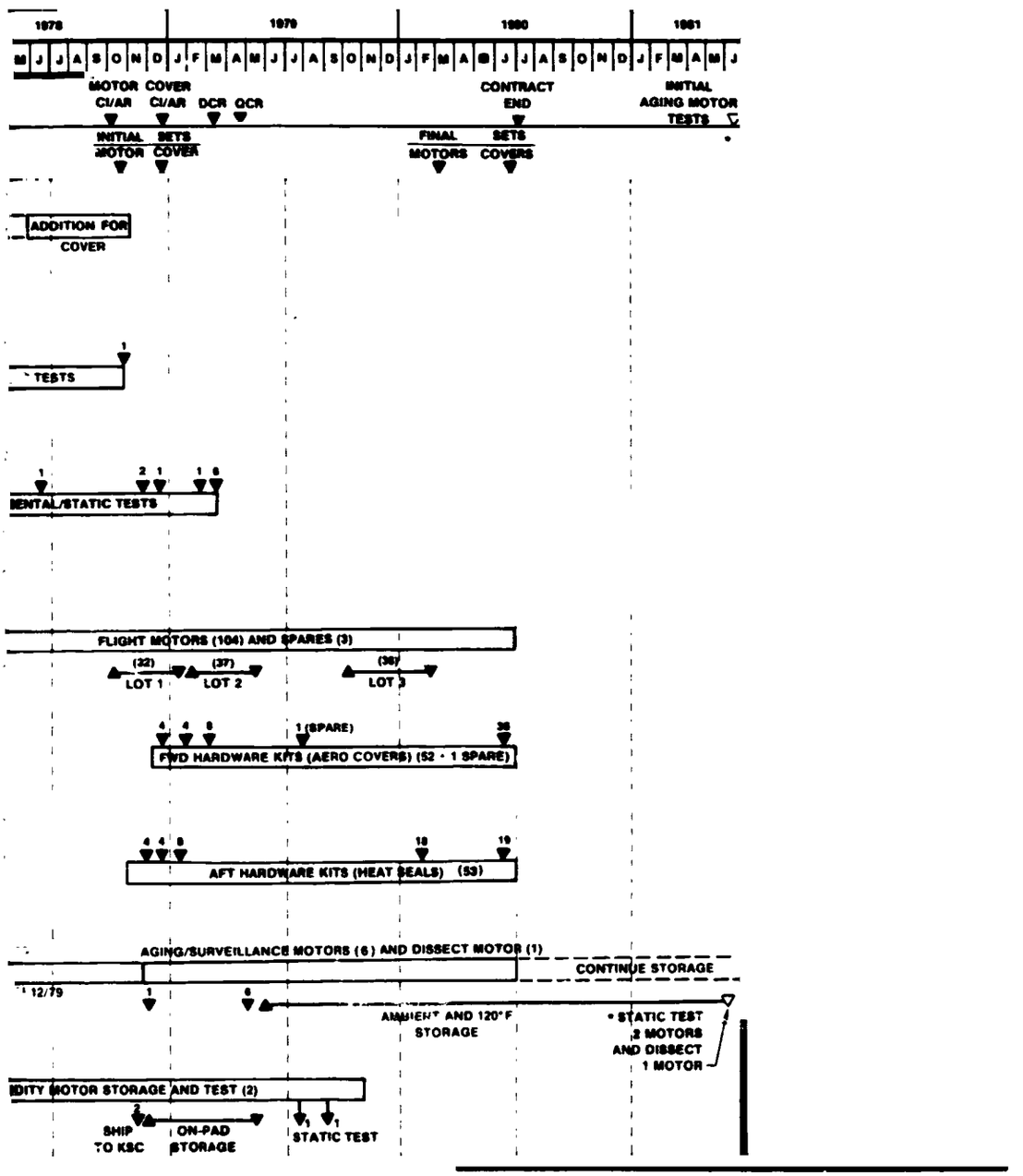


Figure 2-1. Booster Separation Motors Program Schedule

25273

FOLDOUT FRAME 2

The aging and surveillance program was initiated in 1977, with the operational phase starting after the availability of flight hardware in mid-1979. The schedule in figure 2-1 shows the accelerated aging (120°F) motors and a dissected motor being tested in mid-1981. The ambient temperature motors remain to be tested in 1984.

The humidity motor test program consisted of assembly and storage of one forward BSM and one aft BSM on-pad at Kennedy Space Center (KSC) for 6 months, with subsequent static testing of these units at Chemical Systems Division (CSD). The test data indicated no degradation as a result of the on-pad storage conditions.

The booster staging motor program was successfully concluded on 30 June 1980. As stated above, only the operational surveillance phase of the aging and surveillance test program remains. This is planned to be accomplished under a separate contract in mid-1981 and in 1984.

The overall conclusions of the program were that the BSM designs met all requirements of the specification and would perform satisfactorily in flight. These conclusions were supported by the results obtained on the successful STS-1 flight of 12 April 1981 prior to publication of this report.

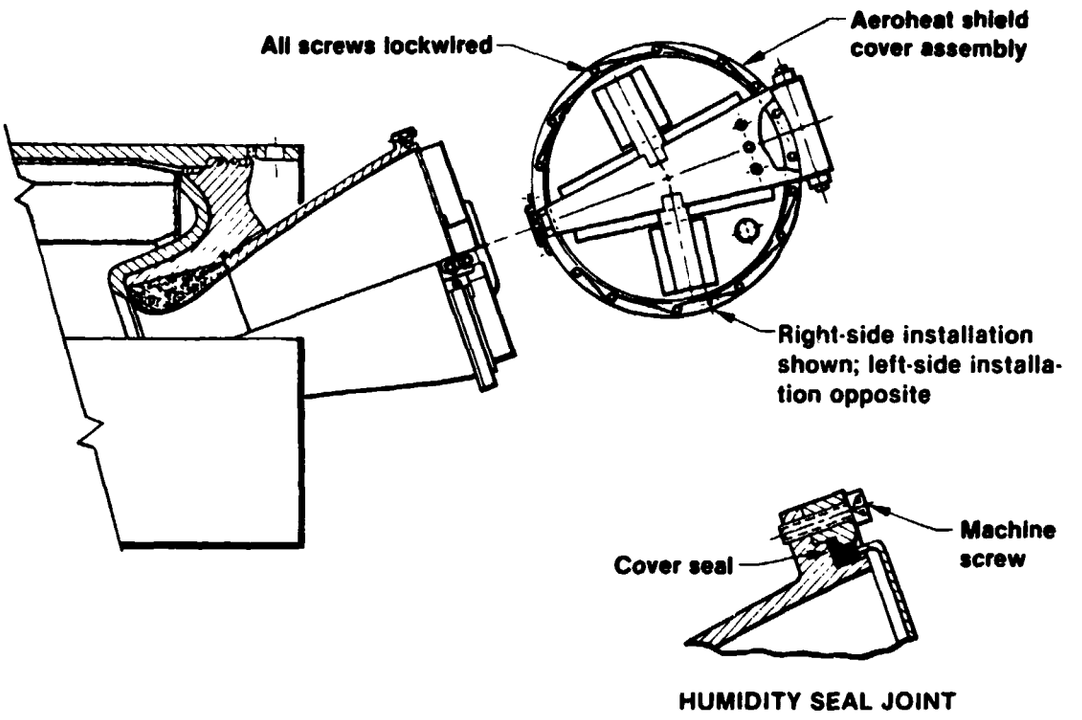


Figure 2-2. BSM Forward Flight Configuration with Aeroheat Shield Cover
V-12225

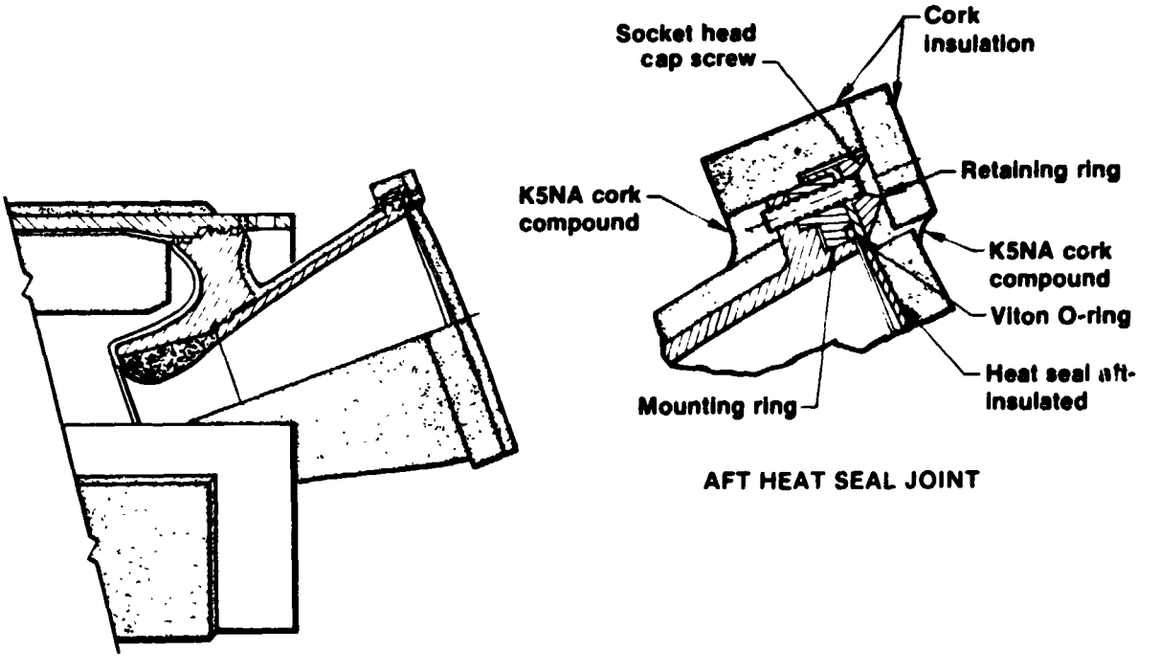


Figure 2-3. BSM Aft Flight Configuration with Aft Heat Seal
V-12226

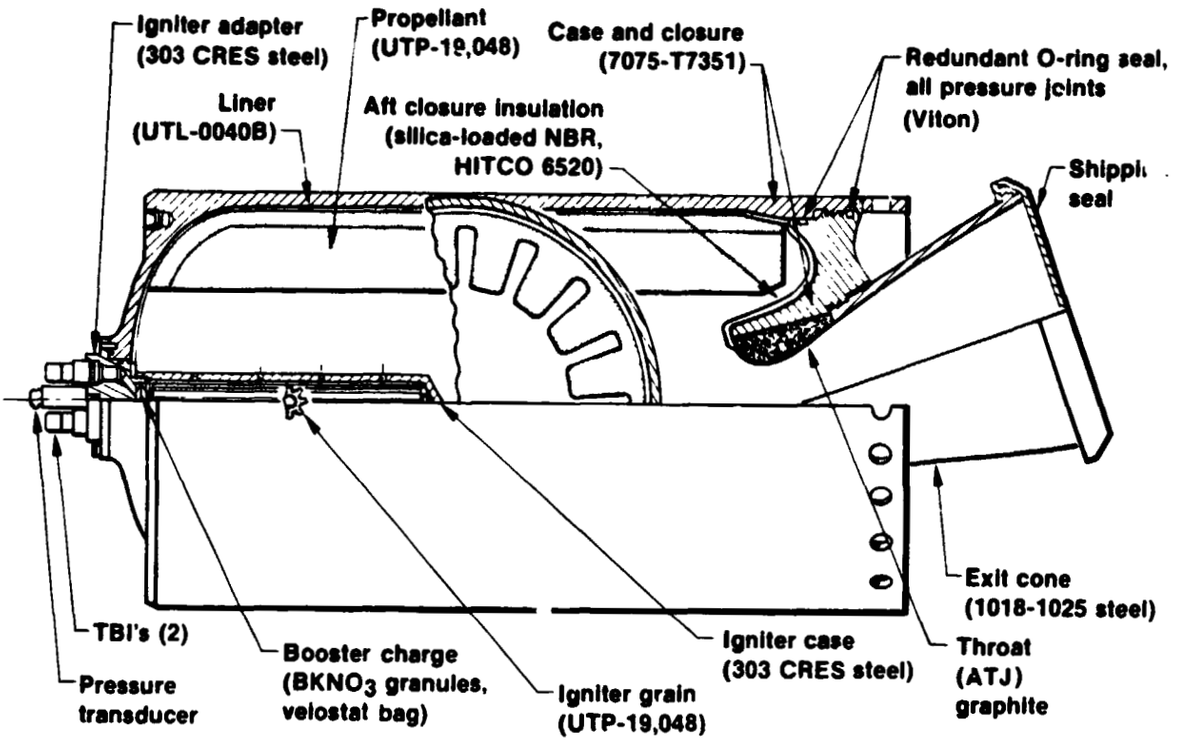


Figure 2-4. BSM Forward Shipping Configuration

V-12224

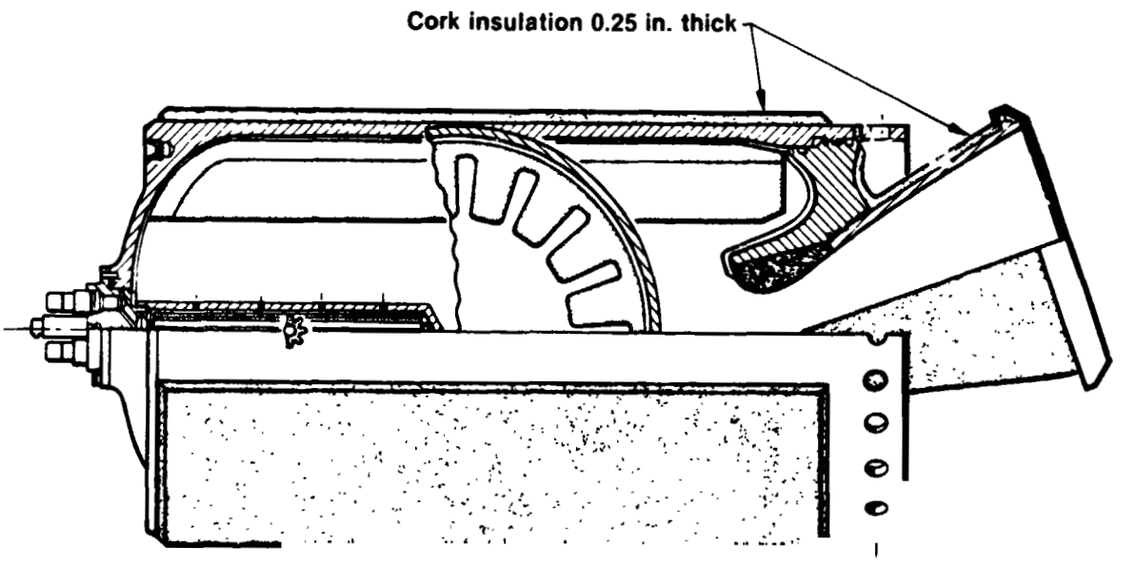


Figure 2-5. BSM Aft Shipping Configuration

V-12314

3.0 SUMMARY DISCUSSION OF PROGRAM DEVELOPMENT TASKS

3.1 MOTOR (DEVELOPMENT)

The purpose of this task was to establish a program to develop a Booster Separation Motor, applicable to the Space Shuttle Solid Rocket Booster, which meets the requirements of the BSM Model Specification, dated 18 August 1975, and the Interface Control Document (ICD) 3-44007, dated 5 November 1976.

CSD fulfilled this task during the period from 25 August 1975 through 30 June 1980 via the completion of the effort described in the following paragraphs.

3.1.1 Design and Development Plan

The purpose of this task was to conduct the development program in accordance with a contractor-generated design and development plan (DDP). The plan is defined by Data Requirement SE-2(M) and was to include all the specified design, development, and test functions called for by the National Aeronautics and Space Administration (NASA) SOW and model specification including those for the aeroheat shield and heat seal added by Supplemental Agreement (S/A) 54.

CSD complied with this requirement by preparing and submitting the "BSM Design and Development Plan," CSD 5180-85-1. Approval was given by NASA to the Revision A, Change 1 version of this plan, dated 17 December 1975.

3.1.2 Design Reviews

The purpose of this task was to establish requirements for formal design reviews consisting of a PDR, a CDR, and a QCR. The reviews were required to give progressively greater detail and substantiation of the designs at the successive phases of the program completed in accordance with the schedule. By means of S/A 54, it was specified that separate PDRs and CDRs be held for the aeroheat shield. CSD accomplished these reviews as described in the following subsections.

3.1.2.1 PDR - Motor

The motor PDR was held at CSD on the 12th and 13th of February 1976. Final close-out of all review item descriptions (RIDs) was accomplished and

design approval received via Marshall Space Flight Center (MSFC) letter EE11 (BSM 76-10), dated 3 March 1976.

3.1.2.2 CDR - Motor

The motor CDR was held at MSFC on 14, 15, 16, and 17 June 1977, during which a total of 70 RIDs were generated. Final closeout of all RIDs was accomplished and design approval received via MSFC letter EE11 (BSM 79-7), dated 5 March 1979.

3.1.2.3 QCR

The QCR for the BSM including covers (aeroheat shield and aft heat seal) was held at MSFC on 9 April 1979. This milestone event occurred after completion of the 14-motor qualification test program. At this time, a Certification of Qualification was prepared for the Booster Separation Motor and approval by NASA was completed on 1 June 1979.

3.1.2.4 DCR - Design Certification Review

This additional special review was held to meet NASA requirements to certify all designs of the SRB and its subsystems and components prior to first flight. CSD participated in this review during a session held at MSFC on 21 March 1979. Written inputs were provided by CSD for incorporation into the NASA documentation for this review.

3.1.2.5 PDR - Cover

The cover PDR was held at CSD on August 21 through 31, 1977. A follow-on review was completed at MSFC on 21 and 22 September 1977. Design approval was received via MSFC letter EE11 (BSM 77-60), dated 26 September 1977, based upon close out of 15 RID items.

3.1.2.6 CDR - Cover

The cover CDR was held at MSFC on 24 and 25 January 1978. A total of 28 RIDs were generated. Final closeout of all RIDs was accomplished and design approval was received via MSFC letter EE11 (BSM 79-7), dated 5 March 1979.

3.1.3 Subsystem and Vehicle System Tests

3.1.3.1 Contractor System Testing

3.1.3.1.1 Compatibility

The purpose of this task was to demonstrate compatibility between the Government-furnished ignition system and the forward and aft BSM clusters.

CSD successfully completed this task by test firing qualification motors Q-2 (at 30°F) and Q-6 (at 130°F), which were equipped with Government-furnished ignition harnesses. The test configuration in each test consisted of the four-motor, confined detonating fuse (CDF) ignition harness connected to the igniter of the BSM and to three other open-air mounted igniters, all equipped with dual TBIs. Both tests resulted in simultaneous ignition of all igniters as required.

3.1.3.1.2 Initiator Redundancy

The purpose of this task was to demonstrate initiator redundancy by firing both single and dual initiators in full-scale motor tests. Also, one additional initiator test was to be performed with (1) a single initiator off-loaded by 15%, (2) a booster charge reduced by with 15%, and (3) an igniter grain off-loaded by 15%.

This task was fulfilled by the successful testing of the two prequalification motors and eight of the 14 qualification motors wherein only one TBI was actuated. The combined 15% offload conditions were successfully demonstrated on the PQ-2 prequalification motor.

3.1.3.1.3 Shock and Vibration

The purpose of this task was to determine the shock and vibration levels generated by operation of the BSM. The desired data were to be obtained by two accelerometer measurements for each of the three main axes.

This task was fulfilled by using accelerometers on all eight development motors, three each mounted on the motor case and three each mounted on the nozzle. Examination of the test data showed no anomalous behavior and a copy of these data was provided to NASA for analysis and evaluation.

3.1.3.1.4 Review and Analysis of Ground Tests

The purpose of this task was to assure that no deleterious effects would occur in the flight program by analyzing performance data obtained from BSM system and component static tests. This analysis was intended to discover or identify any trends, deviations, and biases which might possibly have an impact on the flight program.

CSD fulfilled this requirement with analyses, evaluation, and assessment of data performed throughout the development, prequalification, qualification (verification), and production motor acceptance test program. Appropriate design changes were made on the basis of data obtained at various early stages of the program. Data from the numerous tests of the final configurations during qualification and batch acceptance testing show no indications that any deleterious effects will occur.

3.1.4 Strength and Stress Analysis

The purpose of this task was to assure adequate structural integrity of each BSM component as well as the complete motor assembly.

CSD accomplished this objective by performing the specified analyses on the BSM propellant grain and all inert components. Adequacy of the designs are documented in the following detailed structural analyses:

- "Booster Separation Motor Stress Analysis Report," CSD 5180-76-2, Revision B, dated 12 September 1978
- "Booster Separation Motor Aeroheat Shield Cover Stress Analysis," CSD 5180-78-56, Revision B, Change 1, 2 April 1979
- "Booster Separation Motor Aft Heat Seal Structural Analysis," CSD 5180-78-55, Change 1, dated 22 September 1978.

3.1.5 Fracture Control Plan

The purpose of this task was to generate and implement a fracture control plan for all BSM components to assure structural integrity and serviceability throughout their service life.

CSD complied by preparing and submitting the "Fracture Control Plan" (CSD 5180-75-10), whose initial draft was submitted on 21 October 1975. This plan evolved through several revisions and the final approved plan was submitted on 14 December 1976.

Evidence of satisfactory attainment of all the fracture control plan requirements is contained in "Results of Fracture Mechanics Analysis and Testing," CSD 5180-77-20, Change 1, submitted to NASA on 28 August 1978.

3.1.6 Combustion Stability

This task required early stability analyses and testing of candidate propellant formulations to aid in the selection process for the BSM propellant. In addition, it required testing of the final propellant in the actual motor geometry to verify stable combustion under operating conditions even when an externally induced chamber pressure pulse was applied to the motor. The purpose was to verify that uniform, predictable performance was obtained with no high pressures that could exceed component limits.

T-burner testing and stability analyses were performed on candidate propellant formulations to assure stable performance of the propellant selected for the BSM.

Pulse motor firings were conducted during the development program and results reported in the "BSM Development Motor Test Report," CSD 5180-77-17, dated 5 May 1978. Pulse testing was also performed on the two prequalification motors as discussed in the "BSM Certification Report," CSD 5180-75-109, dated 30 April 1975. All data verified that the propellant and motor system operated in a completely stable manner.

3.1.7 Chamber Pressure Measurements

The purpose of this task was to determine an optimum location and an optimum method for mounting a flight pressure transducer on the motor to obtain in-flight chamber pressure measurements.

CSD design studies supported by NASA concluded that the optimum location for a pressure transducer was in the forward end of the motor entering the chamber through the igniter adapter. This location was also usable for installation of pressure transducers for all ground testing of the BSM. For the one in four flight motors equipped with transducers (-02-00 and -04-00 configurations), the transducers are installed and safety wired in place during final factory assembly before the motor leak check is made. The flight motors without transducers (-01-00 and -03-00 configurations) are equipped with plugs installed in the transducers ports of the igniter adapters.

3.1.8 Environmental Tests

This task was revised via Change Order 36, which was issued after completion of the development motor testing and imposed additional environmental test requirements. The original environmental test requirements were accomplished and reported in the "Development Motor Test Report," CSD 5180-77-17. The additional test requirements were to be verified on two prequalification test motors (see subsection 3.1.9 below) prior to initiating the qualification test series in which these environments would also be applied to the following test articles:

Test	Motor Type
Humidity and salt fog*	Forward and aft
Aeroheating†	Forward
Vibration and temperature*	Forward and aft
Re-entry vibration*	Forward (posttest)
Shock*	Aft

CSD accomplished all the above environmental tests in accordance with the "BSM Prequalification Motor Test Plan," CSD 5180-78-4, Revision B, Change 2. During the vibration tests of the forward motor, the frangible link of the aeroheat shield failed. An investigation was conducted and design and procedural changes were made to correct the deficiency. Subsequently, the new design

* Added by Change Order 36
† Revised by Change Order 50

aeroheat shield assembly was vibration tested on an inert motor, remated with the prequalification motor, and successfully static fired on 1 November 1978. The aft configuration prequalification motor, PQ-2, experienced no problems as a result of environmental tests and was successfully test fired on 16 March 1978 after completion of these tests.

3.1.9 Prequalification Test Motors

This task, added via Change Order 36, provided the test articles for the environmental tests specified in subsection 3.1.8 above and also served as test articles for the two additional pulse firings described previously in subsection 3.1.6.

These motors were successfully tested and results were reported in the "BSM Certification Report," CSD 5180-75-109. All test objectives were completed satisfactorily, permitting initiation of the verification program.

3.2 VERIFICATION PROGRAM (QUALIFICATION)

This section summarizes the verification program tasks.

3.2.1 General

This SOW paragraph established the primary objectives to be accomplished by the verification process and required the preparation and implementation of a verification program to meet these objectives either by test, analyses, or a combination of the two.

CSD prepared the "Qualification Test Plan," CSD 5180-77-16, whose original submittal was made to NASA on 20 May 1977 to fulfill the verification planning requirements. The final issue of this report, approved by NASA, was Revision D, Change 3, which was submitted on 14 March 1979. The requirements of this plan were implemented by CSD, and BSM qualification activities were carried out during 1978 and completed in March 1979. These activities culminated in the submittal of the "BSM Certification Report," Volumes I and II (CSD 5180-79-109, dated 30 April 1979).

3.2.2 Verification by Test

This SOW paragraph defined verification by test, which is a formal demonstration under controlled conditions and procedures to verify that the flight configuration motor assembly meets the design requirements.

Verification that the BSM assembly met each of the requirement paragraphs of Specification CPSC 0726, Part I, is indicated in the "BSM Certification Report," Volume I, and is specifically summarized in table 2-2, pages 8 through 21, of that report.

3.2.3 Certification by Analysis

This paragraph defined verification by analyses where testing is not feasible or there is a need to extrapolate data beyond performed test limits.

Table 2-2 of the "BSM Certification Test Report" identifies those BSM requirements whose fulfillment CSD verified by this method.

3.2.4 Verification Test Procedures

This SOW paragraph requires the preparation of test procedures for each test to be performed and specifies the content of these procedures.

CSD used test procedures which were incorporated in the test plan or included in the specific operations and quality records (O&QRs) applicable to the operation or article. Samples of these procedures are provided in Volume II of the "BSM Certification Report."

3.2.5 Verification Test Controls

3.2.5.1 Hardware Configuration

This task requires that verification hardware be identical to flight hardware and that any deviations from the flight configurations be documented and approved by NASA. Change Order 44 added cork insulation to four aft qualification motors.

This requirement was fulfilled in accordance with the requirements of the "Configuration Management Plan," CSD 5180-75-4, which strictly controlled the

BSM configurations during the verification program, including the installation of the cork insulation.

3.2.5.2 Test Readiness Review

This task established the requirements for a test readiness review prior to the start of verification testing.

The pretest readiness review covering both the prequalification and qualification motors was held at CSD on 15 March 1978. Minutes of this review were transmitted to NASA.

3.2.5.3 Constraints

This task prohibited adjustments or repair of test items during verification testing.

This requirement was fulfilled by adherence to the configuration control procedures and was monitored by strict quality assuance (QA) surveillance of all verification testing.

3.2.5.5 Failure Reporting and Corrective Action

This task establishes the rules for failure reporting, prohibits a "no test" disposition, and outlines corrective action requirements.

CSD complied with these requirements as evidenced by submittals of the following problem and resolution reports: CSD 5180-78-40, CSD 5180-78-41, CSD 5180-79-93, and CSD 5180-79-113.

3.2.5.6 Reverification

This task establishes the conditions under which reverification testing is required, and the action to be taken if any of the conditions exist.

CSD performed no reverification testing during the verification program.

3.2.6 Test Reports

This task established the requirement for verification test reports per Data Requirement TM-3(M).

CSD completed this requirement via submittal of the "BSM Certification Report," CSD 5180-79-109.

3.3 SUPPORT EQUIPMENT AND TOOLING

This task required the contractor to design and develop the support equipment and tooling (SE&T) necessary to support all non-launch site activities of the program. The task included inspection, process and test tooling, special test equipment (STE), handling equipment, and shipping containers.

This task was completed with the fabrication and procurement of all required tooling and equipment necessary to conduct the program. Tooling lists were generated and maintained throughout the program and, at the conclusion of the program, the items were inventoried and stored for use on future BSM production.

3.3.1 Design Engineering and Test Support for Vehicle Activities

This task required the contractor to furnish a list of recommended SE&T which might be used at NASA centers and the SRB assembly contractor's facility. Additionally, the contractor was to review NASA and vehicle contractor documents specifying test requirements and acceptability criteria for compatibility with the BSM system.

CSD provided a recommended SE&T list to MSFC for review and consideration. CSD also performed reviews of SRB documents to assure compatibility of the BSM system with the SRB. As a result of this task, CSD provided a leak test fixture, P/N 80337-002B, to be used at the appropriate field sites.

3.4 OTHER END ITEMS AND SPECIAL ANALYSES

3.4.1 Mock-up

3.4.1.1

This task required the fabrication and maintenance of one full-scale BSM hard dimensional mockup for interface definition and other engineering activities.

CSD completed an engineering mock-up to assist in interface and motor envelope definitions.

3.4.1.2

This task required the fabrication and delivery of four up-to-date BSM configurations to be used for checkout of BSM handling equipment and installation procedures at appropriate field sites.

CSD fulfilled this mock-up requirement in September and November 1977. Two each of the inert mock-up motors were shipped on 9 September 1977 and accepted via DD-250 No. 5180-0002 executed on 19 September 1977. The final two units were shipped on 18 November 1977 and accepted via DD-250 No. 5180-0003, executed on 25 January 1978.

3.4.2 Aging Surveillance Program Plan

This task established the requirement for the generation and implementation of an aging surveillance program plan to provide assurance that the operational reliability of the BSM would be maintained for a period equal to or greater than the required service life of the BSM. Emphasis was placed on (1) the collection of pertinent and valid data, (2) the characterization of modes and criteria, (3) the generation of service life estimates, and (4) the compilation of data for failure diagnosis. Aging surveillance status reports were to be submitted on an as-required basis.

CSD generated and submitted the "Aging Surveillance Program Plan," CSD 5180-75-12, on 30 October 1975. The Revision A issue of this plan, dated 8 January 1976, was approved by NASA on 10 April 1976. DCN 1 to this document was released on 30 May 1979 to update the quantities of surveillance motors from production batches, to update the schedules to reflect actual cast dates, and to update the organization chart.

The aging surveillance program consisted of four specific areas of activity as described below.

3.4.2.1 Environmental Simulation

Bond-in-tension (BIT) JANNAF stress/strain and strand burn rate test samples were to be tested over 48 months at three temperatures and two humidity levels.

Results obtained from samples stored for 12 months were reported in Technical Note 5180-TD-12, January 1978. All data through the 48th month are provided in CSD 5180-81-159, dated 19 February 1981.

3.4.2.2 Sampling

The range of propellant properties at high, nominal, and low specification limits was to be tested for composition, JANNAF stress/strain, and cured strand burn rate values.

This effort was successfully completed and the data were provided to NASA as Attachment I of CSD 5180-77-2, dated 10 February 1977.

3.4.2.3 Accelerated Aging Tests

Propellant and propellant-liner-case samples were to undergo accelerated aging at two temperatures and be tested at 0-, 3-, 6-, 9- and 12-month intervals for JANNAF stress/strain, peel strength BIT, and cured strand burn rate values.

This effort was successfully completed and the data were provided to NASA in Appendix I of CSD 5180-79-134, dated 21 December 1979.

3.4.2.4 Operational Surveillance Program

This task required the manufacture of six BSM motors and appropriate samples from production batches to be tested after 2 years of 120°F accelerated aging storage (three motors) and after 5 years of ambient storage (three motors). One additional motor was also to be stored for 2 years at 120°F and then to be dissected and sample tests performed.

This effort has yet to be completed because of the long storage period (2 and 5 years) and delays in the processing of production motors. The accelerated aged motor firings and sample and dissection motor testing are presently scheduled to take place in June 1981. The 5-year ambient motor firings and sample testing are scheduled to occur in June 1984. At the present time, provisions have been initiated to perform this testing and reporting under separate contract with United Space Boosters Inc. (USBI).

The results of all data presently at hand indicate that the BSM motors will function as required throughout the 5-year service life when handled and stored in accordance with established procedures.

3.4.3 Mix Acceptance Motor Tests

This task required the contractor to static test two motors from each production propellant batch. These motors were to be randomly selected and the production motors from these batches were to be accepted only after approval by NASA of the test motor data. Test data was to be provided via informal flash test reports.

This effort was successfully completed and all pertinent test data were provided via the required flash reports as follows:

Production Batch No.	Flash Report No.	Date
1	CSD 5180-78-57	20 September 1978
2	CSD 5180-79-100	27 February 1979
3	CSD 5180-79-120	27 July 1979

3.4.4 Configuration Management

This task required the conduct of a configuration management program in accordance with SE-019-31-2H during the BSM program.

CSD complied with the above requirements by generating and implementing the "BSM Configuration Management Plan," CSD 5180-75-4, dated 28 August 1975.

3.4.5 BSM Case Master Interface Tool

Change Order 6 directed the design, fabrication, inspection, and delivery of one BSM case master interface tool each for use by McDonnell Douglas Corporation.

CSD complied with this direction upon delivery of the BSM Case Master Interface Tool, P/N B12018-T20, GPID #25041-00, Drawing and Inspection Report to the McDonnell Douglas Corporation via DD 250 No. CSD-001, dated 11 November 1976.

4.0 DELIVERABLE BOOSTER SEPARATION MOTORS

4.1 GENERAL

This task required the contractor to fabricate, assemble, inspect, acceptance test, check out, and deliver 104 BSMs in accordance with the requirements of the Contract End Item (CEI) Specification CPSC 0726A and Interface Control Document ICD 3-44007 per the delivery schedule of Exhibit G.

CSD completed the delivery of 52 forward and 52 aft BSMs and associated mechanical hardware sets for a total of 104 flight deliveries.

4.2 CONFIGURATION

This task required that the configuration baseline to be defined as the one established in accordance with the CDR (see subsection 3.1.2). Moreover, this task required that the baseline serve as the initiation point for formal change approval of Class I engineering changes.

CSD complied with this requirement with the imposition of formal configuration control and accountability at CDR.

4.3 FABRICATION

This task required the fabrication, assembly, test, and inspection requirements to be in accordance with CEI CPSC 0726A, the quality assurance program requirements of paragraph 7.3.1, and other approved program plans as appropriate.

CSD fulfilled the requirements of this task throughout the flight BSM production phase of the program. All flight motors were manufactured and accepted in accordance with the requirements of the CEI; the approved fabrication, process, and test procedures; and the QA inspection and test procedures.

4.4 PREPARATION FOR DELIVERY

This task required the BSM to be delivered in a sealed shipping container with all external openings equipped with protective closures and protective

covers for any critical components subject to damage during shipping, handling, modification, and maintenance activities. A motor log book was to be delivered with each motor. Preparation for shipment was to be in accordance with the provisions of the quality assurance program and the model specification.

Shipping containers were provided for the BSM deliveries and each motor was packaged in accordance with NASA-approved packaging handling and transportation records (PHTRs). Individual motor log books accompanying each BSM noted the manufacture and acceptance history as required by the QA requirements.

4.5 INITIAL RELEASE OF MOTORS TO FABRICATION

This paragraph established the requirement of NASA approval of p ses and fabrication procedures upon satisfactory completion of the CDR.

CSD complied with the requirements of this paragraph with the initiation of production motor fabrication upon NASA's approval of the CDR.

4.6 MANUFACTURING PLAN

This task required the contractor to prepare and implement a manufacturing requirements implementation document.

CSD complied with this requirement by generating and submitting the "Manufacturing Requirements Implementation Document," CSD 5180-75-11, on 24 Octob r 1975.

4.7 INSULATION OF AFT MOTORS

Change Order 44 to the contract stipulated that the 52 aft BSMs and aft heat seals were to be insulated with cork and that the contractor provide cork insulation kits and procedures to complete the cork installation at KSC.

CSD complied with the requirements of this task by providing 52 appropriately insulated motors, aft heat seals and aft heat seal mechanical hardware sets as directed by this change order.

4.8 CDF INITIATOR QUALIFICATION

Change Order 16 to the contract directed the delta qualification testing of 32 CDF initiators, P/N 10A00461-X1, Type I, Series A, +5° indexing configuration. All documentation associated with this testing was to be submitted to NASA for review. Delivery of 60 each of these initiators was to be completed in place at Space Ordnance Systems (SOS) for the Separation Nut Program.

CSD proceeded to complete this task as directed; however, these units, made and tested by SOS, did not successfully complete the test program.

Change Order 57 subsequently directed an electron beam weld qualification program and the performance of a delta qualification program using EB welded TBIs. Upon successful completion of the delta qualification program, a total of 240 EB-welded TBIs were to be delivered.

CSD successfully completed this task and delivered 240 TBIs apportioned two each to 104 flight BSMs, six aging and surveillance BSMs, and six batch acceptance BSMs, with four pairs provided as spares. In addition, 39 TBIs were delivered in place at SOS for use by NASA on the Separation Nut Program.

4.9 DELIVERY OF FIRED MOTOR HARDWARE

4.9.1

Change Order 55 directed the contractor to reassemble, without propellant, two fired BSM qualification motors, inspected and accepted to the applicable requirements of ICD 3-44007, and deliver both to McDonnell Douglas Astronautics Co. in Huntington Beach.

CSD complied with this direction and completed the shipment to McDonnell-Douglas via DD-1149 dated 29 June 1978.

4.9.2

Change Order 63 directed the contractor to reassemble, without propellant, one fired BSM qualification motor, inspected and accepted to the applicable requirements of ICD 3-44007, and ship this motor to KSC for use by USBI.

CSD complied with this direction and assembled one fired BSM qualification unit and shipped this unit to MSFC on 14 September 1978 via CSD Shipping Order 021552.

5.0 SPARE PARTS

The contractor was required to identify and recommend a list of BSM and SE&T spare parts to NASA for approval. This list was to identify items by P/N, description, quantity, use, location, delivery schedule, consumption rate, and cost.

CSD provided a recommended list of BSM and SE&T spare parts as required by this task. Spares provided under this contract consisted of the following:

- Four pressure trandsucers - P/N 16A 03044-1
- One aeroheat shield (cover only) - P/N B12881
- Two BSM forward motors - P/N B12000-01-01
- One BSM aft motor - P/N B12000-03-01

6.0 MAINTAINABILITY (M)

This task required the contractor to establish and implement a maintainability effort to assure that the design of the BSM and support equipment would allow the optimum achievement of operational and support requirements of the Space Shuttle program.

Although no specific separate Maintainability (M) Program was performed on the BSM program, CSD incorporated the basic principles of M in the initial BSM designs and during the design evolution from a single configuration to four separate configurations. Demonstrations performed by USBI have verified the satisfactory M aspects of the BSM.

7.0 PROGRAM MANAGEMENT AND SUPPORT

All managerial functions and assurance tasks necessary to coordinate, complete, and report the specified contract work were to be supplied by the contractor to effectively define, implement, control, monitor, evaluate, and revise as required.

7.1 PROGRAM DIRECTION

This task required the contractor to manage, control, and report the following:

- Development, manufacture, and operational phases of the program
- Coordination and program liaison with MSFC, Space Shuttle Vehicle contractors, and other contractors and Government organizations as appropriate
- Periodic technical and management reviews of all work under this contract.

CSD established a program management organization to provide the direction and to perform the managerial functions necessary to conduct the program. This management organization directed all phases of the program culminating with the final flight motor deliveries. Reporting occurred monthly and all program reviews, both formal and informal, were supported.

7.2 DATA

7.2.1 Deliverable Data

7.2.1.1

The contractor was required to provide data necessary for MSFC management visibility and technical direction per Interface Requirements Document (IRD) SE-019-024-2H(M), Exhibit L, to the contract.

CSD generated and submitted required program plans and reports throughout the BSM program to provide MSFC with program status and visibility of the ongoing effort.

7.2.1.2

The contractor was required to provide a set of engineering design drawings and associated process and manufacturing documents and lists to MSFC.

CSD complied with this requirement with 23 submittals of the requested engineering documentation. These submittals continued throughout the program to provide MSFC with the most recent issue or revision of the engineering documentation.

7.2.1.3

Change Order 36 required the contractor to provide duplicate sets of frequency modulated (FM) data tapes of all BSM firings, along with appropriate documentation, to enable analysis of the test data.

FM tapes and data printouts of all BSM prequalification and qualification static tests were shipped to MSFC for their review and analysis.

7.2.2 Other Data

The contractor was required tc retain the supporting data used in the implementation and execution of the contract for review by the Government upon request.

CSD maintained all supporting data throughout the program and used this data in the performance of the program reviews, audits, and certifications.

7.3 ASSURANCE DISCIPLINES

This task required the necessary labor and material to accomplish the effort defined by the program plans, disciplines, and systems created to assure that the end products meet the intended program stanards. Plan requirements were defined in Exhibit L of the contract.

CSD generated, implemented, and maintained the plans as prescribed by Exhibit L and discussed in the following subsections.

7.3.1 Quality Assurance Program

7.3.1.1

This task required the contractor to implement and maintain an effective quality inspection system meeting the requirements of NHB 5300.4(1c) (see subsection 7.3.1.2).

7.3.1.2

The contractor was required to submit an inspection system plan in accordance with DR RA-15(M) which satisfied the requirements of paragraph 7.3.1.1 above.

CSD generated and submitted the "Inspection System Plan," CSD 5180-75-3, on 15 August 1875. Revision A of this plan was submitted on 29 September 1975 and was approved by MSFC on 29 October 1975.

7.3.1.3

This paragraph permitted the use of a Material Review Board (MRB) upon approval of the Inspection Plan and Contracting Officer authorization. The use of deviation approval requests (DARs) was also invoked by this paragraph.

CSD conducted an MRB as authorized and submitted DARs for hardware deviations affecting any BSM component critical feature.

7.3.1.4

The contractor was required to submit end item acceptance test procedures in accordance with DR RA-19(M).

CSD provided the end item acceptance test procedures via CSD 5180-78-52, dated 1 September 1978.

7.3.1.5

This paragraph required the contractor to furnish all contractor or subcontractor workmanship specifications and standards for review by MSFC.

The workmanship specifications and standards employed on the BSM were provided to MSFC for review during the configuration inspection/acceptance review in September 1978.

7.3.1.6

This paragraph required the contractor to submit material and component qualification test procedures to MSFC for approval.

CSD generated and submitted test procedures covering BSM material and component qualification as prescribed by DR-RA-20(M).

These submittals were provided as follows:

- "Material and Component Qualification Test Planning," CSD 5180-78-25, dated 25 April 1978
- "Ignition System Cluster Test Planning and Procedures," CSD 5180-78-42, dated 25 May 1978
- "CEI Acceptance Test Procedures," CSD 5180-78-46, dated 28 June 1978
- "Weight Plan BSM Qualification Test," CSD 5180-78-2, Revision A, dated 25 July 1978.

7.3.1.7 Problem Reporting and Corrective Actions

This paragraph required the contractor to perform or provide the following items regarding problems and corrective action:

- Commence non-conformance reporting at the start of drawing release and maintain throughout the program
- Devise a storage and rapid retrieval system for non-conformance information.
- Implement and maintain a closed-loop system to effectively monitor, resolve, and feed back all nonconformance information in a timely manner
- Provide problem and resolution reports and problem summary reports.

CSD incorporated the requirements of this paragraph through the implementation of the "Inspection System Plan," CSD 5180-75-3, Revision A, dated

19 September 1975. Problem and resolution reports and problem summary reports were generated and submitted during the program to highlight the status of special program problems as prescribed in DR RA-10(M).

7.3.1.8

The contractor was required to submit an end item acceptance data package for each CEI.

CSD provided an end item data package as prescribed by DR-RA-17(M) for each CEI delivered under this program.

7.3.1.9

The contractor was required to submit a CEI limited life items list and limited life waivers, as appropriate.

CSD submitted the CEI limited life items list per DR RA-9 (M) via CSD 5180-77-9 on 6 May 1977. No limited life waivers were required under this program.

7.3.1.10

The contractor was required to maintain a listing of critical processes.

CSD provided the BSM critical processes list per DR RA-23 (M) to MSFC via CSD 5180-77-19 on 6 May 1977.

7.3.2 Safety Program

The contractor was required to (1) generate a hazards analysis procedure and provide a risk management summary (hazards), and (2) submit accident/ incident reports as necessary.

CSD provided the hazards analysis procedure per DR RA-21 (M) via CSD 5180-75-15 on 29 December 1975, with Change 1 submitted on 14 July 1976. The risk management summary per DR RA-13(M) (CSD 5180-76-4) was submitted on 27 January 1976. Change 1 to this document was provided to MSFC on 14 July 1976 and Change 2 was provided on 11 April 1978. A total of seven accident/incident

report submittals per DR RA-14(M) were made during the BSM program. Quarterly accident/incident summaries were provided as part of the monthly technical report.

7.3.3 Traceability

This paragraph required the contractor to provide traceability in accordance with MSFC Drawing SE-019-33-2H.

CSD generated and implemented the "BSM Traceability Plan," CSD 5180-TP-8500-1, Revision A (dated 4 August 1976), which fulfilled the requirements of this task.

7.4 PROGRAM REVIEW MEETINGS

The contractor was required to support, with necessary personnel, the following program reviews:

- Preliminary design review (PDR) at MSFC
- Critical design review (CDR) at MSFC
- Qualification certification review (QCR) at CSD
- Quarterly program reviews (QPRs) at MSFC
- Monthly reviews (if scheduled) at CSD
- Test readiness reviews at CSD

CSD provided the necessary personnel to support the PDRs, CDRs, and QCR as described in subsections 3.1.2 herein. The QCR was held at MSFC rather than at CSD. Additionally, a DCR at MSFC was supported by CSD as described in subsection 3.1.2.

Two configuration inspection/acceptance reviews (one in September 1978 for motors and one in December 1978 for covers) were also held during the program just before the initial shipment of motors and covers.

The qualification test readiness review was successfully completed at CSD on 15 March 1978.

7.5 PROGRAM PLAN APPROVALS

This paragraph identified the approval status of the following plans previously provided to MSFC:

- "New Technology Plan," CSD 5180-75-2, approved issue dated 11 September 1975
- "Configuration Management Plan," CSD 5180-75-4, approved issue dated 25 August 1975
- "Design and Development Plan," CSD 5180-75-1, Revision A, approve issue dated 19 September 1975
- "Inspection System Plan," CSD 5180-75-3, Revision A, approved issue dated 19 September 1975.

8.0 AEROHEATING SHIELD (AHS)

This section of the SOW was added via Supplemental Agreement No. 54 based upon the necessity to provide a distinctly separate design for forward and aft BSMs. The Aeroheating Shield Program was to be performed in three phases as described below.

8.1 PHASE I - AEROHEATING SHIELD FEASIBILITY STUDY

This phase provided for a feasibility study to determine the most desirable approach to accommodate an aeroheating shield (AHS) on the forward BSM. A report of the results of the phase I effort was to be provided to MSFC.

CSD conducted a significant amount of effort during the feasibility study phase, which was reported on in CSD 5180-76-14, dated 9 August 1976.

8.2 PHASE II - DESIGN AND DEVELOPMENT

Phase II of the AHS program was to consist of the design and development of two alternate cover concepts and was to include full-scale testing on demonstration motors and the vibration of a nozzle-cover subassembly. This task also included the fabrication, assembly, and test of two humidity motors of each configuration (forward and aft) which were to be subjected to a 6-month storage time at KSC.

CSD completed the design and development phase of the AHS program with successful demonstration of two cover concepts. One concept was based on a retractable cover design and the other on a hinged cover design. The hinged cover was chosen as the most appropriate design and was subjected to in-depth development tests for design refinement and eventual qualification and production. The phase II effort was reported via CSD 5180-78-69, dated 4 January 1979.

After CDR, a cover test failure occurred wherein the frangible link failed during a prequalification motor vibration test. Subsequent evaluation of the design and test parameters and features led to an improved cover design and a test program incorporating revised, more realistic test conditions.

Two humidity motors, one forward and one aft, each equipped with its appropriate cover, were subjected to 6 months of on-pad storage at KSC. The aft motor was successfully test fired on 12 July 1979. The forward motor could not be installed normally in the test stand because a mislocated motor case mounting hole prevented installation in the test stand. However, the test stand attachment holes were modified to accept the motor and the forward humidity motor was successfully test fired on 12 September 1979. Results of the humidity motor tests were reported in CSD 5180-80-152, dated 12 March 1980.

8.3 PHASE III - FLIGHT AND QUALIFICATION HARDWARE FABRICATION

This phase of the AHS program was to consist of the fabrication of AHSs for use in qualification testing and for flight motor deliveries. It also included any modifications required to exit cones, shipping containers, or aft heat seals.

CSD simultaneously provided AHS covers for both qualification testing and flight motor deliveries to support NASA flight schedules. CSD successfully qualified the AHS design as described in the "BSM Certification Report," CSD 5180-79-109, dated 30 April 1979. Final deliveries were completed on 21 June 1980, with the shipment of 36 AHS sets together with 19 aft heat seal sets.

8.4 AEROHEAT SHIELD CONFIGURATION

This paragraph establishes the configuration of the AHS to be as identified via Change Order 28, with all the CDR RIDs and comments incorporated.

CSD complied with this requirement in the performance of the Phase III effort discussed above.